Tilting Motion of the Ground as Related to the Volcanic Activity of Mt. Aso

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and

Micro-Process of the Tilting Motion of Ground and Structure

By

Yoshiro Itō

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by

Yoshiro Itō

(Communicated by Prof. E. Nishimura)

Abstract

Tilting motion of the ground was observed with two sets of high sensitive tiltmeters at two points near the active crater of Volcano Aso. From the present observation it was clearly ascertained that the ground of the crater rises and sinks in accordance with the volcanic activity in a considerably large amount. It is certainly serviceable for forecasting the volcanic eruption and prevention of volcanic disaster.

1. Introduction

The history of geological and geochemical investigation of active volcanoes could be traced back to the old time, but the commencement of their geophysical research belongs to a comparatively recent time. Various methods, such as the seismological observation of volcanic earthquakes and volcanic micro-tremors, the levelling and gravity survey of volcanic area, the geomagnetic and geoelectric survey and observation, and other geophysical methods have been, since the beginning of the present century, increasingly applied for investigation of the nature of active volcanoes. Especially in our country, many active volcanoes— Asama, Aso, Sakurajima, Mihara, Usu and some others— have been successfully investigated by many Japanese geophysicists for the purpose of explaining geophysically the volcanic phenomena, specially detecting any change forerunning volcanic eruptions, that would give warning and mitigate the volcanic disaster. For example, K. Sassa (1) has studied in detail the volcanic micro-tremors related with the activity of Volcano Aso and succeeded in finding a law which enables foretelling of volcanic eruption by the observation of volcanic micro-tremors. T. Minakami (2) has studied fully the nature and behavior of Volcano Asama by applying

the various geophysical methods of investigation, and he successfully warned, in several cases, the volcanic eruption, saving many lives. He gave the warning of volcanic eruption of Asama by judging danger of eruption, mainly from observation of some kind of local and volcanic earthquakes, the tiltmetric observation at volcanic area, and some other measurements.

Concerning the observation of tilting motion of ground in volcanic area, T. A. Jaggar (3) has early tried to detect any relation between the tilting motion of a volcano ground and its volcanic activity from his tiltmetric observation near a crater. K. Sassa (1) observed, in 1931-1932, the change of ground-tilt with a tiltmeter of Rebeur-Paschwitz type set up at underground of the Aso Volcanological Laboratory, 7 km distant from its active crater, and has found some peculiar ground-tilting connected with the volcanic activity. T. Minakami (2) has also found some peculiar tilting motion of the ground which precedes an eruption of Volcano Asama by carrying out tiltmetric observations with Ishimoto's silica tiltmeter setting up at several points around the active crater.

Under the circumstances above mentioned, a systematic observation of tilting motion of ground in the volcanic area of Aso was commenced by E. Nishimura (4) in 1937. The instruments were fused silica tiltmeter of horizontal pendulum of Ishimoto's type, and the observation points were four—Kenkyusho, Senrigahama, Miyaji, and Hondo as represented in Fig. 1. But these observations were interrupted by some unfortunate occurrences such as

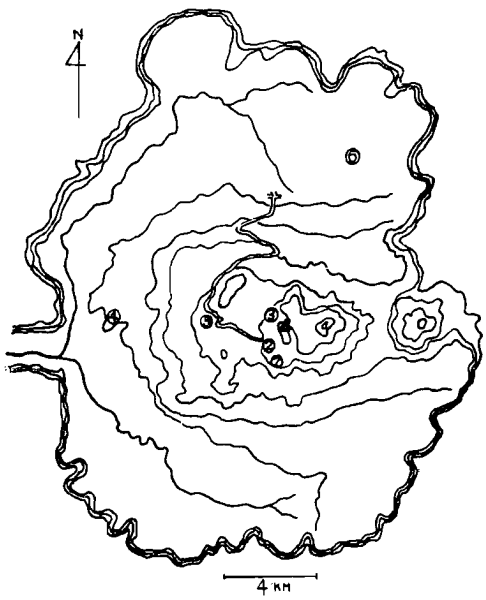


Fig. 1. Regional map of Volcano Aso
1 : First Crater, 2 : Hondo, 3 : Umanose, 4 : Volcanological Laboratory, 5 : Senrigahama, 6 : Miyaji, 7 . Sarayama

the Second World War and others after four years' observations. After the end of war Hondo was first reopened in 1953; and Kenkyusyo, in 1957, and Senrigahama was programmed to be opened in 1960. Meanwhile some new stations have been set up for tiltmetric observation at Aso, especially near the crater which are also represented in Fig. 1. Stations at Umanose in 1953, Sarayama in 1959 and Ōhira in 1960 were already, or will recently be, opened for continuous tiltmetric observations. Consequently the total number of tiltmetric observation stations in Aso area in the coming year, will be six and will become greatly be serviceable for the study of ground-tilting connected with the volcanic activity. In the present article the observed data obtained at two stations of Hondo and Umanose during 1953-1959 are discussed and some consideration on the peculiar tilting motion of the ground related with the volcanic activity will be given.

2. Tiltmetric Observations at Hondo and Umanose

Volcano Aso is situated at the central region of Kyusyu Province. Its highest mountain named Takadake is 1592 m high above sea level and the ground rock formation is andesite. The large caldera of diameter of 23 km NS and 18 km EW is world famous for its ground feature, and, at present, the four active craters are formed in the mountain named Nakadake (1500 m in height). Among them, the crater named the First Crater (see Fig. 2) is the most active, and really, in recent times, the eruptions of 1927-1929, 1930, 1933 were severe. Among them the eruption in 1933 was the most violent, and after the great eruption of 1933, some comparatively calm period of twenty years elapsed. But, on April 27, 1953, a small but severe eruption suddenly took place at the First Crater and a number of people was either killed or injured. Against these disasters, two tiltmetric observation stations were set up, in May and August, 1953, at Hondo and Umanose close to the First Crater for observation purposes of anomalous ground-tilt which precedes a volcanic eruption. Such an observation is a branch of the research project for forecasting volcanic eruptions aiming at previous warnings of eruption and mitigation of the damages to life and property caused by such eruptions, the research method being, in this case, to detect the phenomena

which precede a volcanic eruption by observation of the change of mode of volcanic microtremors, anomalous tilting motions of the gound, anomalous geomagnetic variations, a change of gravity and others which are

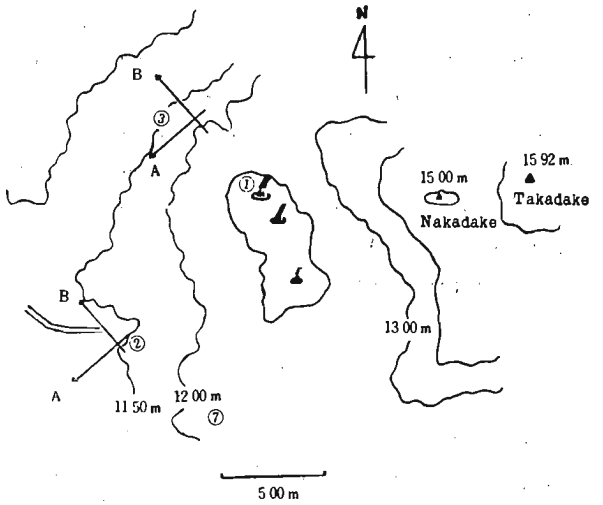


Fig. 2. Positions of the First Crater (1) and observation stations of Hondo (2) and Umanose (3).

Fig. 3a Observation room at Hondo.

Fig. 3b Observation room at Umanose

observed at several places around the Volcano Aso.

In the present article, the data of tiltmetric observation at two places nearby the First Crater of Hondo and Umanose are reported and discussed. Hondo and Umanose stations are situated at a point 1000 m (SW), and at 500 m (NW) from the First Crater respectively, as seen in Fig. 2. At Hondo an observation was made in an underground room of reinforced concrete building on a volcanic rock, and at Umanose the observation room was a small wooden building on lava flow as seen in Figs. 3a and 3b. The instruments used were tiltmeters of horizontal pendulum type of Zöllner suspension made of super-invar alloy, and the records were exchanged once a week; examples of the observed tiltgrams at both stations being represented in Fig. 4.

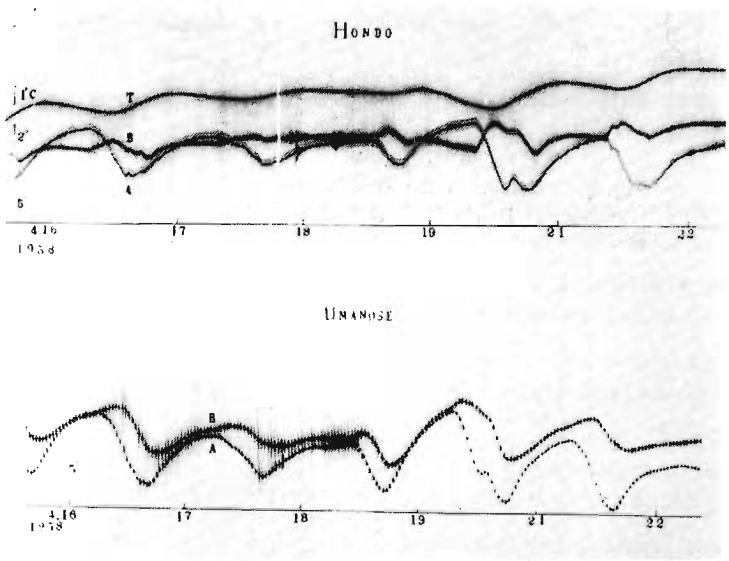


Fig. 4. Tiltgrams at Hondo and Umanose.

3. Tilting Motion of the Ground at Hondo and Umanose

The epochs of tiltmetric observations treated in the present article at Hondo and Umanose were May, 1953—February, 1959; and August, 1953—June, 1958 respectively. In tiltmetric observation at such shallow seated rooms as those of Hondo and Umanose, the daily variation of

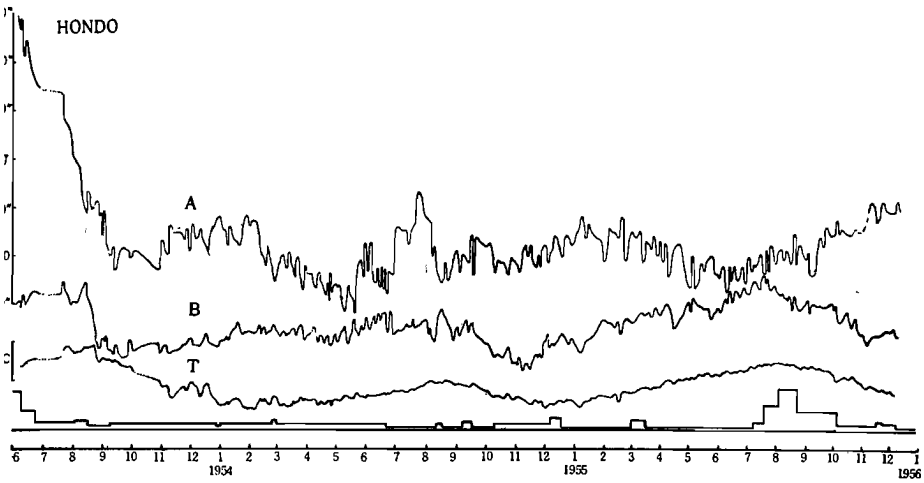


Fig. 5. Secular ground-tilting observed at Hondo (1953—1956). A, B, and T show the ground-tilting towards the First Crater, its orthogonal direction and room temperature respectively.

ground--tilt was, in general case, large, and moreover the tiltgram was strongly disturbed by the effect of rainfall. In addition, the annual variation of ground-tilt was also observed large or small according to the condition and circumstance around the room (e. g. topography, weather and others). For the purpose of treatment of an anomalous tilting motion of the ground presumed to be connected with the volcanic activity, these changes of meteorological origin must completely be excluded from the observed data. The mean amount of daily tilting motion was roughly estimated to be 7″-9″ for Hondo and 5″-15″ for Umanose respectively. These daily variation was easily eliminated by taking an average of 24 hours' values of the day. Concerning the elimination of annual variation, it was a difficult problem, especially in the present

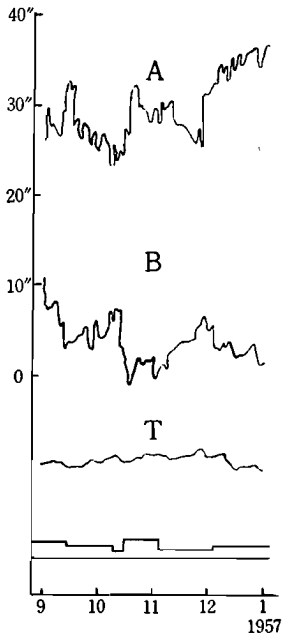


Fig. 6. Secular ground-tilting observed at Hondo (1956-1957).

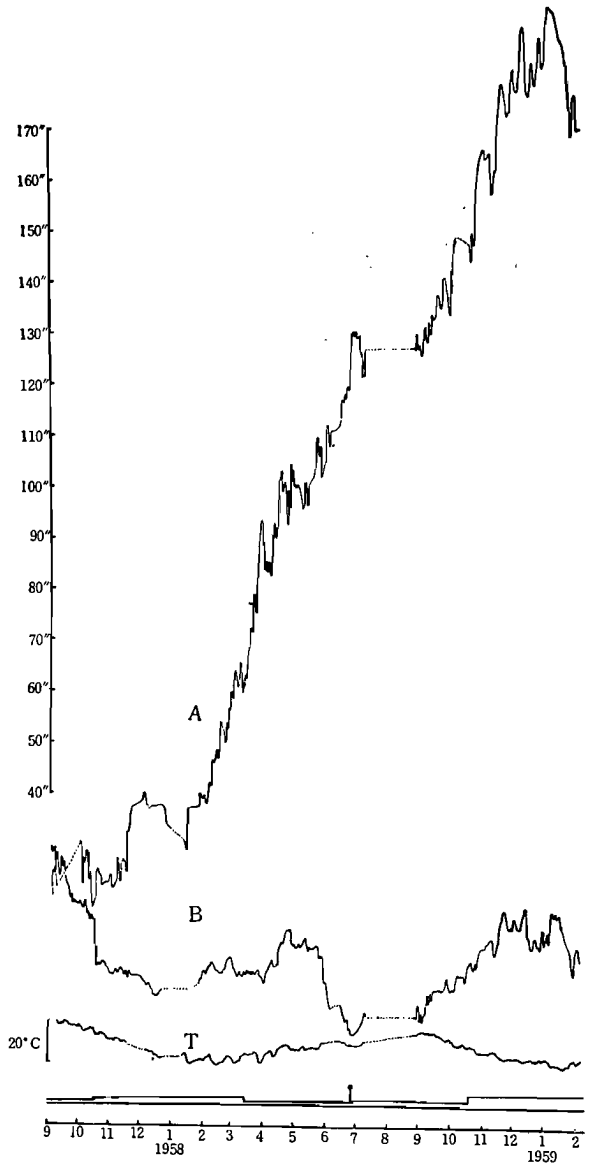


Fig. 7. Secular ground-tilting observed at Hondo (1957-1959).

case. Because the amount and mode of annual variation were affected by the amplitude of annual variation of atmospheric temperature and strongly controlled by the condition of precipitation through the year, especially by the activity of rainfall in the wet period (June-July) and the heavy rain caused by the passing of typhoon. In the case of treatment on the secular change of ground-tilt covering some several years, the annual change could easily be eliminated by taking an overlapping mean of 12 months. But in such a case as the present discussion on the anomalous change of ground-tilt related with the volcanic eruption, where the expected duration of anomalous change was for some several months or less, the above mentioned method of 12 months' overlapping was

inadequate for the present problem. Under these circumstances the following treatment was applied to the present observed data.

First the daily variation was eliminated by simply taking an average of 24 hours' values of each day. Thus obtained secular change of ground-tilt are shown in Figs. 5, 6, 7, 8 and 9.

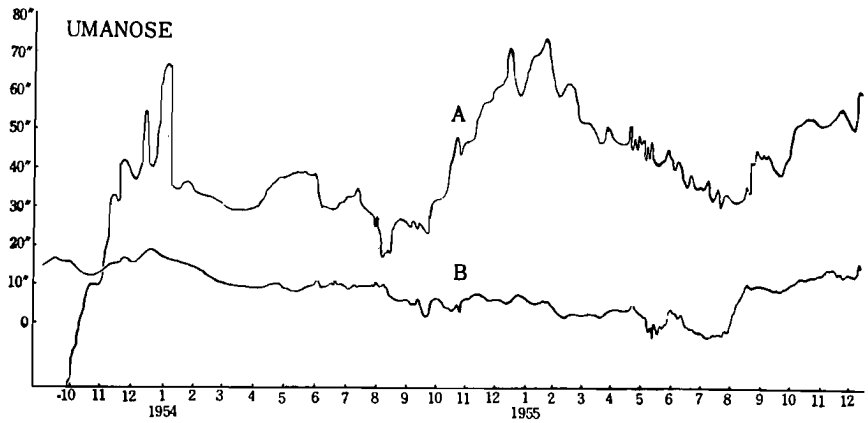


Fig. 8. Secular ground-tilting observed at Umanose. B and A show the ground-tilting towards the First Crater and its orthogonal direction respectively. (1953–1956).

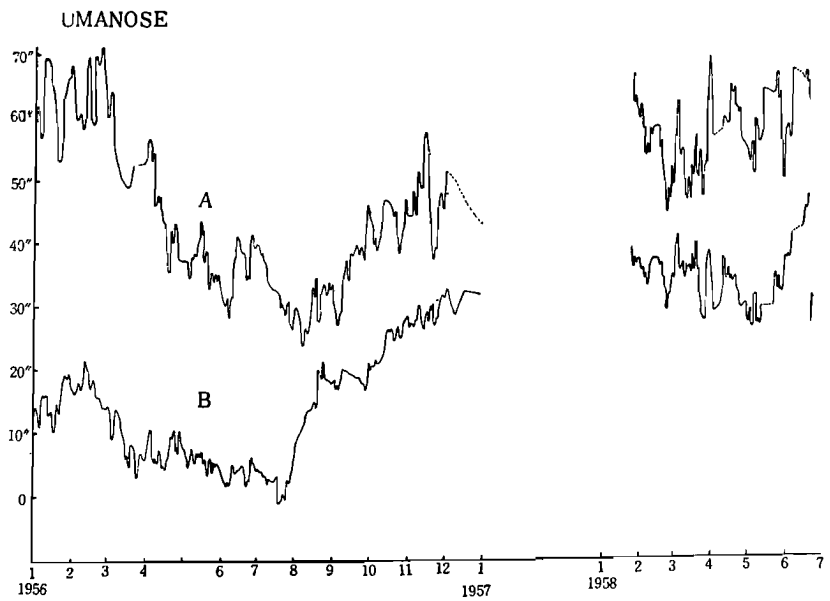


Fig. 9. Secular ground-tilting observed at Umanose (1956–1958).

In the second place, a form of annual variation in the calm period of volcanic activity was tentatively assumed. In detail speaking, the annual variation during January-December, 1939 for Hondo (Fig. 10) and that during January-December, 1956 for Umanose (Fig. 9) were tentatively adopted as a typical mode of annual variation in calm period respectively. Because the period of 1939 selected for Hondo was the most tranquil in volcanic activity of Aso since the great eruption in 1933, and the period of 1956 for Umanose was comparatively calm during the period of present observation (1953-1958). Certainly there remains unsolved the problem of effect by yearly difference in type of annual variation and by a heavy rainfall of long duration, but, in the first step, the argument is given on the data which are obtained by subtraction of an assumedly typical form of annual variation from the above obtained secular change which contains no daily variation. And the effects of meteorological origin which are considered to be uneliminatably remaining in a certain amount will be treated case by case of each volcanic eruption.

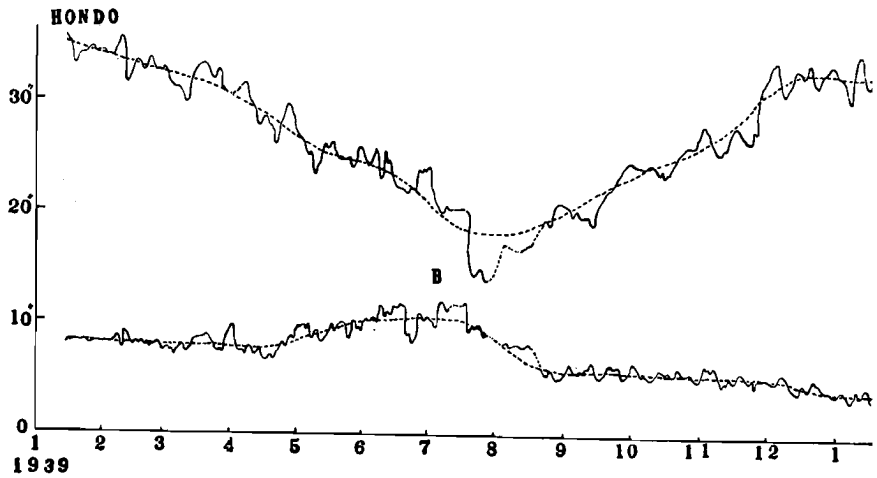


Fig. 10. Normal annual variation of ground-tilting at Hondo.

4. Anomalous Ground-Tilts Related with the Volcanic Activity

In this section residual ground-tilts obtained by the above described

procedure, are discussed in connection with the activity of the First Crater of Volcano Aso. During the present observation the volcanic eruptions of the First Crater deserving description were as follows.

(a) Large eruption in 1953

On April 27-29, May 7, and May 25, a large eruption occurred, ejecting a vast amount of large volcanic rocks to a height of several hundreds meters killing scores of people at beginning of the eruption on April 27.

(b) Small eruption in 1954

There were some eruptions of small scale on April 1-10 and on May 26; and in November-December the crater was somewhat active.

(c) Small eruption in 1955

On July 25, the crater ejected small rocks which dropped at a place 300 m distant from the crater.

(d) Small eruption in 1956

There were small eruption on March 13, and December 21.

(e) Small eruption in 1957

There was a small eruption of April 12, and the crater was somewhat active.

(f) Small eruption in 1957

The crater was somewhat busy during November 3-December 24.

(g) Violent eruption in 1958

On June 24, a violent and sudden eruption took place accompanying a strong burst-wind and ejecting a vast amount of large volcanic rocks and ashes. By this eruption, scores of people were killed and many structures near the crater were completely destroyed.

Certainly these conditions of amount and area of ejected volcanic rocks and ashes, and the height of volcanic cloud, and the duration of eruption were all useful for grading volcanic activities. On the other hand the micro-tremors of ground frequently observed at the area of Volcano Aso were also suitable for expressing quantitatively the volcanic activity. Namely some three kinds micro-tremors of ground were frequently observed in the area of Volcano Aso, and tremors of period of nearly 1.0 sec, 4.0 sec, and 0.5 sec were found by K. Sassa (1) as the first, second, and third kind of volcanic micro-tremors respectively. Appearance of these micro-tremors was very characteristic in correlation

with the eruption, generally with the activity of Volcano Aso. The frequency of appearance and amplitude of oscillation of these volcanic micro-tremors were certainly considered to be quantitatively expressing the volcanic activity. In the present case the maximum amplitude (observed at Hondo) of volcanic micro-tremors of third kind presumed to be directly connected with the volcanic eruption was adopted as a measure of volcanic activity. Really this measure was confirmed to be highly suitable for expressing the grade of volcanic activity, especially of each eruption by comparing this measure with the apparent features of eruption characterized by the amount and area of ejected volcanic rocks and ashes and other various conditions.

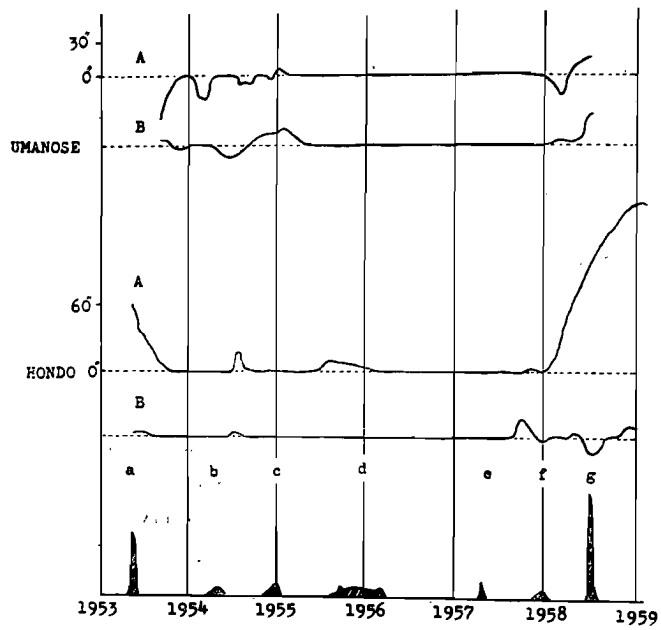
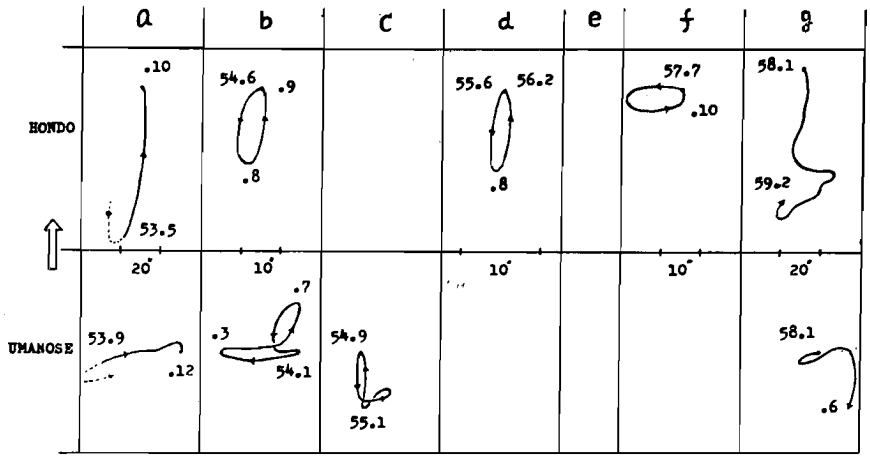


Fig. 11. Residual ground-tilting obtained at Hondo and Umanose.

In Fig. 11, the residual ground-tilts, obtained by the above described procedure at Hondo and Umanose, are plotted in reference of the maximum amplitude of volcanic micro-tremors of third kind for a measure of volcanic activity. Referring to the Figure, some views will here be stated. First, both at Hondo and Umanose after a large eruption of April-May, 1953 a large anomalous ground-tilt was observed. Unfortu-

nately we had carried out no observation before the eruption and consequently the view had to be limited to past eruption problems. At Hondo the downward tilt to NE of the First Crater of nearly 55″ was observed during May-October, 1953. And at Umanose, the downward tilt towards SW, parallel but in reverse to that at Hondo, was observed. These anomalous ground-tilt observed at both stations were considered to be a ground-deformation in recovering stage of a large eruption. In 1954, some residual ground-tilts were also obtained as seen in the Figure, but, the effect of long and heavy rainfall in July-August were considered to have prevailed and controlled the feature of the residual, which remained uneliminated in the procedure of subtracting a mean annual variation of ground tilt from the observed ground-tilt. There was some small eruption during the period of 1955—1958, but a corresponding, remarkable ground-tilt of anomalous character was not observed. This is safely explained by the smallness of energy of the volcanic activity during this period which was insufficient to arouse a large ground-deformation. Concerning the violent eruption of June 24, 1958, large anomalous ground-tilts were observed at both stations early in the beginning of the year, especially the amount of ground-tilt observed at Hondo in the direction of SW, the direction to the crater from Hondo was in the reversed sense, exceedingly large, amounting to more than 150″. In detail speaking, the anomalous ground-tilt presumed to be connected with the present large eruption was somewhat vaguely observed in the beginning of 1957. Namely, the ground at Hondo commenced a NW tilting since April and reversed its direction in June-July finishing its motion in the end of 1957, as seen in the B-component residual in the Figure. While on the other hand, at Umanose, an anomalous tilting to SW in the beginning of 1957 and then to the NE direction in May-June, continuing its motion to the middle of February, 1958, as seen in the A-component residual in the Figure. These anomalous ground-tiltings at both stations connected with the volcanic activity in 1958, were expressed in the vector diagram of Fig. 12. The large ground-tilt to the direction of SE observed at Hondo in 1959 ceased its motion by the end of 1959 and, at present, no remarkable change is observed. Concerning the data at Umanose, the station was destroyed by ejected volcanic rocks of a violent eruption of June 24, and its repair is not yet made.



Fig, 12. Vector diagrams of anomalous ground-tilting observed at Hondo and Umanose. ⇧ shows the direction to the First Grater seen from the respective station of Hondo and Umanose. a, b, c, d, e, f and g correspond to the respective epoch of volcanic activity described in this section.

5. Summary and Discussion

In the present case, two major and some minor eruptions were observed during a period. The two rooms for tiltmetric observation were situated close to the crater, both being several hundreds meters distant and in orthogonal orientation seen from the crater. The residual, secular ground-tilt obtained by subtracting a mean annual ground-tilt from the observed, was discussed with reference to the volcanic activity, especially to the two major eruptions in 1953 and 1958. As seen in Fig. 11, the correlation character between the eruption and ground-tilt was clearly observed at both stations. But the mode of their ground-tilt was not simple and its character in detail was considerably different in mode and behavior with respect to each observation point and each eruption. But, generally speaking, it was conclusive also from the present observation, that the ground around the crater was seen heaving up several months before the large eruption, and the amount of this upheaval was recovered by the subsidence process, immediately in one case and several months later in another case, after the large eruption. Consequently it is safely said that we can foretell a large volcanic eruption by tiltmetric observations at some suitable points around the crater. It should be remarked

that the large, anomalous ground-tilt of more than 100″ observed at Hondo was ascertained to be really existent by the result of precise levelling survey made before and after the large eruption of June 24, 1958, which shows an upheaval of 80 cm of ground at the top of the crater.

Acknowledgement

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